SIMULATION OF NATURAL VENTILATION SYSTEM IN CHEMISTRY LABORATORY OF FACULTY CHEMICAL AND NATURAL RESOURCES ENGINEERING LAB BUILDING

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ABSTRACT

The performance of natural ventilation in buildings is often being performed by using computational fluid dynamics (CFD) software, who's gaining its popularity recently. The main goal for this research is to improve the ventilation system by comparing the performance for the current ventilation system and the modified ventilation system. The air distribution is being focused more in order to predict the performance. Chemistry lab of faculty Chemical and natural resource engineering laboratory building is used as the model. Large Eddy Simulation (LES) is applied to estimate the air distribution of ventilation system in the cubic room of chemistry lab. The ambient temperature and pressure are used to be substitute into numerical model. The numerical result that obtained from the simulation is compared with the existing experimental data which the air change rate of laboratory must be at least 30% less than the standard which the standard value of ACH is in the range of 6 to 12 ACH. As the result, the modified ventilation system is showing the optimum of air change rate inside the chemistry lab. The air change rate for a person inside the laboratory is 9 ACH compared to current ventilation which that the value is over the standard value. As the conclusion, the modified ventilation system of the chemistry lab enhances the performance of the ventilation.

ABSTRAK

Prestasi pengudaraan semulajadi dalam bangunan kebiasaannya dipersembahkan dengan menggunakan perisian bendalir dinamik (CFD), yang mana tahap penggunaannya semakin meningkat dari hari ke hari. Penyelidikan ini bertujuan untuk memperbaiki sistem pengudaraan yang sedia ada dan system pengudaraan yang telah diubah suai. Makmal kimia di dalam bangunan makmal kejuruteraan kimia dan sumber asli dijadikan sebagai model. Large Eddy Simulation (LES) digunapakai untuk menjangka pembahagian udara daripada sistem pengudaraan dalam bilik segi empat padu makmal kimia. Suhu dan tekanan persekitaran digunakan untuk dimasukkan ke dalam model berangka. Keputusan yang diperolehi daripada simulasi dibandingkan dengan keputusan eksperimen yang sedia ada di mana kadar perubahan udara (ACH) di dalam makmal mestilah 30 % lebih rendah daripada spesifikasi yang telah ditetapkan yang mana lingkungannya mestilah berada dalam 6 hingga 12 ACH. Keputusannya menunjukkan sistem pengudaraan yang telah diubahsuai menepati syarat yang telah ditetapkan di mana ACH adalah 9 dan jika dibandingkan dengan system pengudaraan semulajadi yang sedia ada, menunjukkan ianya telah melebihi had spesifikasi yang telah ditetapkan. Kesimpulannya, pengubahsuaian sistem pengudaraan menunjukkan prestasi cemerlang untuk system pengudaraan di makmal kimia.

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LIST OF ABBREVIATION

ACH	Air change per hour
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
CFD	Computational fluid dynamic
CFM	Cubic feet per minute
DC	Direct current
FKKSA	Faculty of Chemical Engineering and Natural Resources
HVAC	Heating, Ventilation, and Air conditioning
IAQ	Indoor air quality
LES	Large Eddy Simulation
P	Pressure
T	Time
VAV	variable air volume
WHO	World Health Organization
2D	2 Dimensional
3D	3 Dimensional

LIST OF SYMBOLS

Cfm	Cubic feet meter
C_7H_5OCl	Benzene Carbonyl Chloride
CO_2	Carbon Dioxide
Ft^2	Feet square
kW	Kilowatt
l	Liter
l/m	Liter per minutes
l/m^3	Liter per meter cubic
l/s	Liter per second
m	Meter
m/s	Meter per second
m^2	Meter square
m3	Meter cubic
m^3/h	Meter cubic per hour
m^3/s	Meter cubic per second
Qins, T	Ventilation rate
O_2	Oxygen
S	Second
s/h	Second per hour
^oC	Degree Celsius

ρ	Density
τ_{ij}	Subgrid scale Reynolds stresses
$\bar{\upsilon}$	Velocity vector
ν	Kinetic viscosity

CHAPTER 1

INTRODUCTION

1.1 Background of study

Ventilation system is a system that relies on the movement of air which it moves either from outside in or inside out and it should be continuously in order to enhance the quality of indoor air (Khan *et al.*, 2008).

The ventilation systems consist of natural ventilation and mechanical ventilation. The natural ventilation can be describe as a system that using a nature phenomena to drive in or out the air from the building. Moreover, mechanical ventilation is simply known as a system that is using a mechanical device such as fan to force the air from the inside to the outside of the building.

Nonetheless, the ventilation system is significant to ensure the integrity of human health (Hooff and Blocken, 2009). The failure of ventilation system will cause some problems that connected with humidity (Fanger, 1971; Wolkoff and Kjaergaard, 2007; Wyon *et al* .2002), overheating, and some sort of odours, smokes and pollutant.

Common effects that related with bad performance of ventilation are shortness in breath, unconscious, and headache. However, the most critical effect involving the failure of ventilation system is it also can cause chronic disease such as lung cancer and asthma.

As the early prevention care method, the ventilated air from a better ventilation system will indirectly decrease the worst effect on human health which by diluting odours and limiting the concentration of carbon dioxide that had been released by the human through respiration process.

1.2 Problem statement

FKKSA Lab is divided into five sub laboratory which are unit operation, chemical reaction, and separation laboratory, clean room, chemistry laboratory, pilot plant, and gas engineering laboratory. The laboratory is situated in a different area and it also equipped with different general ventilation system. The focusing laboratory is chemistry laboratory.

From the observation that had been made, chemistry lab is facing a problem regarding on the lower air distribution. The lower air distributions cause the room to become overheating and it will affect the comfortness of the consumer that using the lab to conduct their experiment. A study on the airflow inside the laboratory should be carry on in order to overcome the problem.

1.3 Objectives

The objective of this research is to overcome the ventilation system problem in chemistry lab of FKKSA Lab by study on the airflow of only considering the natural ventilation system. The chemistry lab model will be simulated by using computational fluid dynamic (CFD).

1.4 Significance of study

This research will improve the airflow for current natural ventilation system in the FKKSA Lab and in the future, the newcomer students and lecturers of the faculty will feel comfy while using the laboratory to run the experiment.

1.5 Research scope

The scope of this research will consist of:

a) Modification on current ventilation system in chemistry lab

b) Simulate the data by using computational fluid dynamic (CFD) software for current and modified ventilation system of chemistry lab.

c) Determination on the air distribution inside the chemistry lab of FKKSA's laboratory

d) Comparison data between the standard air distribution data in laboratory with the current and modified ventilation system in laboratory.

CHAPTER 2

LITERATURE REVIEW

2.1 Ventilation

Ventilation is one of the HVAC systems where all of it (heating, ventilating and air conditioning) relies on the movement of air. Basically, the movement air for ventilation either from outside in or inside out of an enclosed space in a building (Hall and Greeno, 2009; Khan *et al*, 2008).

There are several terms that need to be known related to ventilation in order to comply with human health (Hoof and Blocken, 2009). The movement of air will accommodate fresh air for respiration process where it must contained approximate 0.1 to 0.2 l/s per person and at the same time maintaining the percentage of oxygen (O_2) in the air that is theoretically approximate percentage of 21%. The maintaining of oxygen will control the amount of carbon dioxide (CO_2) which the concentration of CO_2 must less than 2% and if the concentration is too high, it will poison the human health and as the effect, it may cause fatal damage.

Furthermore, the movement of air will limit moisture of the enclosed space where the relative humidity is acceptable around 30% to 70%. Discharge heat from mechanical equipment, human, and lighting, remove odours, smokes, dust and other contaminants, comfort stagnation and at the same time provide a sense of freshness (Etheridge and Sandberg, 1996; Spencer, 1998; Awbi, 2003).

Hence, adequate ventilation system will provide enough air to be distributed inside the building and at the same time, some problems which involving excessive humidity, condensation, overheating, odour, smokes and pollutant can be avoided (Khan *et al*, 2008). It should be continuously from time to time in order to enhance the quality of indoor air (Etheridge and Sandberg, 1996; Oakley, 2002; Awbi, 2003; Khan *et al*, 2008; Hall and Greeno, 2009).

2.1.1 Type of ventilation

There are two types of ventilation system that had been used in the building (Jong and Sang, 2007). The types for the ventilation system consist of;

a) Natural ventilation

Natural ventilation can be describe as a system that using a nature phenomena to drive in or out the air from the building by the opening part such as windows or doors or stack without any mechanical fan. This kind of ventilation system is commonly used because it is an energy consumption saver method (Busch, 1992; Zhao and Xia, 1998) and it also easier to be installed. The natural ventilation system basically depending on wind effects, thermal buoyancy and the combination of wind and thermal buoyancy. Two major types of natural ventilation are;

i. Cross ventilation

It is oftenly used in the tropic climate countries and for certain cases, this system are circumventing from being utilized. The closest example of circumvent of cross ventilation is thick building (Munir and Wonorahardjo, 2004). Hence, in this situation, single sided ventilation is much more suitable to be practiced.

ii. Single sided ventilation

Single sided natural ventilation system is attained by exchanging the air between indoors and outdoors through the same openings on the same side of a space at the equivalent height. In other words, it also can be define by the flowing of air into a space through one or more inlet of the openings and flowing out from different exit openings which when the inlet and outlet openings are at a different levels.

b) Mechanical ventilation

Mechanical ventilation is a ventilation system using a mechanical device such as fan to force the air inside to outside of the building. The fans of the mechanical ventilation system can be built in the opening part of the building such as windows or walls or in the air duct. The figure 2.1 below shows the example of mechanical ventilation, a prototype turbine ventilator incorporating a PV-fan system.

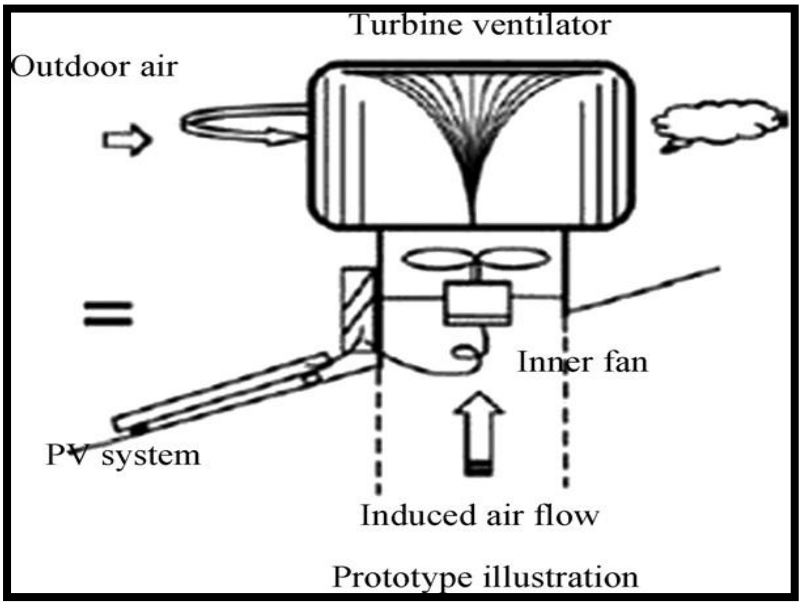

Figure 1: Prototype turbine ventilator incorporating a PV-fan system

Source: Khan, Su and Riffat (2008)

Figure 1 shows the example of mechanical ventilation system which using a small direct current (DC) fan powered by the PV cell. This prototype turbine ventilator can manage to increase the operation and energy efficiency compare with the standard commercial existing ventilator.

Nonetheless, the surrounding condition helps mechanical ventilation system to operate well for example in warm and humid condition. In this kind of situation, infiltration is needed to obviate condensation where the warm moist air from inside the building accessed the wall, roof, or floor and meets cold surface from happening. As the result, the positive pressure of mechanical ventilation system is frequently applied. Positive pressure of the mechanical ventilation system means the room air is escaped out through openings of the building either leakage envelope or windows (WHO Publication Guideline).

However, if it is in cold climate, exfiltration need to be prevented in order to reduce condensation from happening. The negative pressure of mechanical ventilation system applied in cold surrounding. Negative pressure means the room air is actually neutralized by sucking air from the outside (WHO Publication Guideline).

2.2 Laboratory ventilation

2.2.1 Outdoor air requirement in laboratory

There are differences between ventilation system in laboratory and ventilation system in other building because laboratory needs more fresh air in order to neutralize the surrounding.

Table 1: Minimum ventilation rates in breathing zone

Occupancy category	Occupant density	Outdoor air requirement				
		$\frac{cfm}{person}$	$\frac{l}{s\,.person}$	$\frac{Cfm}{ft2}$	$\frac{L}{s.m2}$	Air class
Education						
classroom	65	7.5	3.8	0.06	0.3	1
laboratories	25	5	5.0	0.18	0.9	2
Multi use assembly	100	7.5	3.8	0.06	0.3	1

Source: ASHRAE Standards 62.1-2007, Ventilation for Acceptable Indoor Air Quality

General notes for table 1;

[1] Related requirement: the rates in this table are based on all other applicable requirement of this standard being met.

[2] Smoking: These tables apply for no smoking areas. Rates for smoking permitted spaces must be determined using other methods.

Table 1 shows that the outdoor requirement for laboratory and other places for educational purposes. The occupant density for laboratory is lower than the other because lower occupant density will provide a huge space. Normally, huge space can decrease the possibility of shortness of breath in a confined place compared to a place that surrounds by many people for example classroom (ASHRAE 62.1-2007).

The difference outdoor air requirement between laboratory and other places determine by the function of the place itself. Laboratory is used by the occupant to run some experiment and in the experiment; they are dealing with hazardous chemical. Hazardous chemical is dangerous to all human being and other living life because of its property for example Benzene Carbonyl Chloride (C_7H_5OCl). Benzene carbonyl chloride is a corrosive chemical which high concentration exposure will cause severe irritation and burns and for long term effect, it will cause lung cancer (Guidelines, 1997).

2.2.2 Requirement for laboratory ventilation

The requirement of the design for the new ventilation system depends on the specific needs of the laboratory. Furthermore, the requirement of laboratory ventilation will be as the additional guide in spite of referring to the requirement stated in code and standard

(Laboratory ventilation, 2009). Basic requirement of ventilation system in the laboratory is as follow:

a) General laboratory ventilation

In general, mechanical ventilation should be used in the laboratory. The laboratory ventilation stated that the mechanical ventilation will help to exhaust the fume inside the laboratory to the outside faster than using natural ventilation. In order to provide adequate air for fume hoods, exhaust or stack, and bio safety cabinet, the design of air change rate for each laboratory room is needed and it should be documented. Combination of general and fume hood exhaust will be the preferred ventilation system which the design is only required few cost and little energy consumption. More than that, the design should also be excess in capacity for equipment aging and future expansion (Laboratory ventilation, 2009)

b) Fume hood exhaust system

Fume hood design must be cooperated with user needs, room configuration and general ventilation. The fume hoods functioning as the fume remover by circulate the fume from the fume hoods through stack finally to the outside. It must be situated near the door for at least 6 feet length. Alarm should be provided in case any emergency can be alert such as explosion or fire (Laboratory ventilation, 2009). There are two types of hood that used by the consumer in order to exhaust the fume of the chemical exposure to the outside surrounding.

i) Types of laboratory fume hood

Conventional and bypass is the type of laboratory hood. The differences between those two types of hood are depending on the operational airflow (Labconco, 2003).

Conventional hood had been used for ages. Nowadays, most of the conventional hood had been replaced by the bypass hood which by pass hood can be classified as a superior type performance of hood. The bypass hood can be vary in term of its high performance, auxiliary air and reduced air volume.

I. By pass fume hood

Basically, the constant air volume for by pass hood is constant. It had been design to be sash closed. The condition cause the air to be redistributed, hence minimizing the high velocity of air streams.

In figure 2, the bypass opening located above the sash and below the air foil. Actually, the bypass can reduce fluctuations in face velocity as the sash is being fully or halfly open (Labconco, 2003). However, it cannot achieve the level that required when it relates to face velocity.

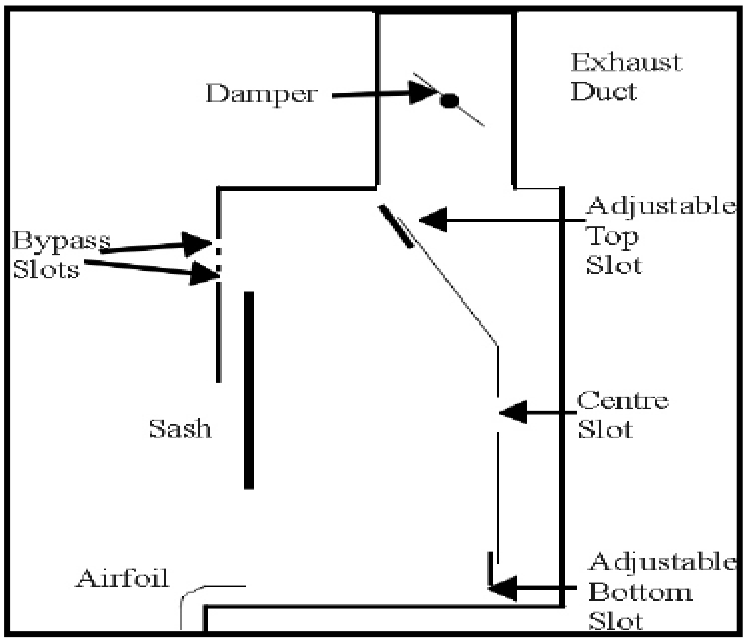

Figure 2: Example of bypass hood

Source: www.safetyoffice.uwaterloo.ca

II. Conventional fume hood

The conventional hood is generally not containing air foil eventhough that the sash is movable (labconco,2003). Moreover, the conventional hood is just a basic enclosure with the interior baffle.

The conventional hood is operating at constant of exhaust volume which is it remains opened to let all of the exhaust air to enter the hood. If the sash of hood is in close condition, the air speed will be higher. This condition will make the important apparatus situated inside the hood being damage. It also will disturb the instrumentation, slowing the distillation rates, cool hot plates and disperse valuable sample.

ii) Fume hood selection requirement

In order to select a suitable hood, the face velocity and containment issues need to be focussed more (labconco, 2003). The issues will give an impact on concentration for contaminants where the concentration of contaminants is significant to be kept as low as possible in order to maintain the ventilation performance for the laboratory.

However, several researcher thought that containment issue is more crucial compared to face velocity issue. Its happen because the higher value of face velocity will cause the movement of fluid become turbulence within the hood where it also prevent the hood to contain containment (Diberndinish, 1999). Hence, the higher value of face velocity is not necessarily good.

2.3 Laboratory ventilation standard

The laboratory ventilation standard is being used to establish the requirement and procedures for the ventilation system which to avoid over exposure of chemical that generated while conducting experiments (ANSI Z9.5). Each of the laboratories is required to follow the standard of ANSI Z9.5 where the laboratory needs to have a 'Ventilation Management Programme'. This kind of programme can emphasize the importance of management ventilation system in term of selection, design and operation of laboratory's ventilation system. A coordinator will be the responsible person to manage the programme in order to make it efficient as it plans. Nonetheless, a test of ventilation system is needed to effectively stress out the purpose of the programme.

2.3.1 Test of ventilation system

The periodic test on ventilation system is significant to be done to improve the performance of the ventilation system even though that the face velocity of the hood was optimum. The testing will be done as stated in ASHRAE 110-1995.

The testing of performance for ventilation system according to ASHRAE 110-1995 is done by doing three part of test. Part one; the test should be tested in term of its face velocity profile. The optimum face velocity will be in range of 60-100 fpm. Part two; the test should undergo smoke generation of titanium tetrachloride and part three, the test should undergo tracer gas containment by using sulfur hexafluoride which the sulfur hexafluoride needs to be released for 4 liters per minute (*l*/m).

2.3.2 Variable air volume systems

Variable air volume (VAV) system is one of the required matters in evaluating the performance of the ventilation system. The air volume is measured by the sash opening multiply by average velocity desired (Labconco). The satisfied of variable air volumes is 10 percent (10%) per foot of hood for cubic feet per minute (CFM) that is fully open.

2.3.3 Exhaust stack discharge

The exhaust stack discharge of hood needs to be in vertical direction with a minimum of 10 feet, above the contiguous of the roofline (Newman). The purpose of the height is to avoid the students or workers from looking directly to the discharge of fluid through the stack. Other than that, the discharge stack also needs to be situated with respect to the air inhalation to prevent reentry of fluid. The flowing of fluid needs to be from lower to higher hazard in order for controlling the exposure. Hence, the discharge velocity is expected to be at least of 300 fpm.